Development of a local power generation system by using ferromagnetic resonance

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The purpose of our study is deveropment of a local power generation system by using ferromagnetic resonance (FMR). In spintronics, studies aiming at reducing energy loss and power saving have been widely conducted. On the other hand, our study is focused on the aspect of generating electromotive force (EMF) from the viewpoint of energy creation.

The inverse spin-Hall effect (ISHE) is observed even in a ferromagnetic metal (FM) $Ni_{80}Fe_{20}$ "single-layer" without non-magnetic metal layers under the FMR [1]. However, except for the $Ni_{80}Fe_{20}$ [1], the EMF property generated in a "single-layer structure" FM film itself under the FMR has not been investigated yet. So, in this study, in order to observe the EMFs in iron (Fe) and cobalt (Co) single-layer films under the FMR condition and clarify the origins of the EMFs in FMs under their FMR, the voltage properties generated in FM an Fe and a Co films under the respective FMR condition were investigated at room temperature.

Fig. 1 shows the sample structure. FM films with the thickness of 25 nm were prepared on Si/SiO_2-substrates by using an electron beam deposition system. After film formation, the sample substrates were cut to be the sample area size of 1.5 × 4.0 mm^2. Leading wires for measuring the EMFs in the FM films were directly connected to the both edges of the films by using silver paste.

We succeeded to observe the EMFs in the Fe and Co single-layer films under the FMR [2]. The saturation magnetization calculated with FMR condition is 1330 emu/cc for Fe, and 1169 emu/cc for Co, respectively. We used equations (1) and (2) to analyze three following effects; ISHE, anomalous Hall effect (AHE), and planer Hall effect (PHE) [1],

$$V(H) = V_{ISHE}\frac{\Gamma^2}{(H-H_{FMR})^2+\Gamma^2} + V_{AHE}\frac{-2\Gamma(H-H_{FMR})}{(H-H_{FMR})^2+\Gamma^2} \quad (1),$$

$$V_{PHE} = -\frac{1}{2}wJ_1\rho_A\cos\theta_M \times \frac{h\gamma\left\{2\alpha\omega\cos\varphi - \left[4\pi M_S\gamma\cos^2\theta_M + \sqrt{(4\pi M_S)^2\gamma^2\cos^4\theta_M + 4\omega^2}\right]\sin\varphi\right\}}{2\alpha\omega\sqrt{(4\pi M_S)^2\gamma^2\cos^4\theta_M + 4\omega^2}} \quad (2).$$

As the analyzing results, as origins of the EMF, the self-induced ISHE in Fe and Co single-layer films was dominant, and respectively 2.1 and 18 times larger than the AHE which is one origin of the simultaneously observed EMFs under the FMR as shown in Fig. 2. When we set the calculated ISHE is respectively 7.1 and 73 times larger than the calculated PHE by eq. (2), we could explain experimental data well as shown in Fig. 3. Thus, we concluded that the ISHE was main in EMFs observed in the Fe and Co single-layer films under the FMR.

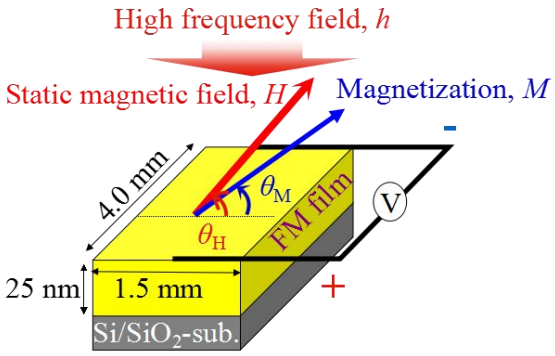

Fig. 1. Sample structure.

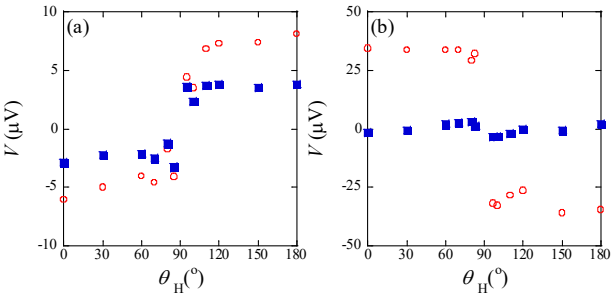

Fig.2. θ_H dependence of the EMFs for (a) an Fe sample and (b) a Co sample under the FMR with the microwave power of 200 mW. V_{ISHE} (open ciecles) and V_{AHE} (solid squres) correspond to the coefficient of the first and second terms in the eq. (1), respectively.

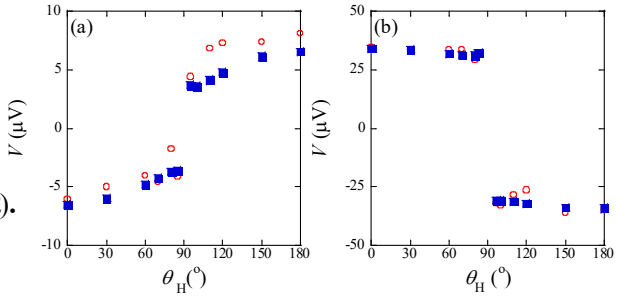

Fig. 3. θ_H dependence of comparison between the experimentally obtained EMFs (oprn circles) and the theoretically obtained EMFs (solid squares) for (a) an Fe sample and (b) a Co sample.

[1]A. Tsukahara, *et al*., Phys. Rev. B **89**, 235317 (2014).
[2]K. Kanagawa, *et al*, cond-mat.arXiv:1610.06695(2016) .